Accelerated Development of Innovative Clean Energy Systems : Post-K Project Priority Issue 6

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FLAGSHIP 2020 Project

Priority Issue 6

Accelerated Development of Innovative Clean Energy Systems

(Leader : S. Yoshimura, UTokyo) (2014.12-2020.3)

Sub Issue A : Energy Conversion Systems Accompanied by **High-pressure Combustion and Gasification**

(Leader : S. Yoshimura)

Sub Issue B : Advancement of **Fuel Cell** Design Process

(Leader : N. Shikazono, UTokyo)

Sub Issue C : High-efficiency Wind Power Generation System (Large Scale **Offshore Wind Farm**)

(Leader : A. Iida, Toyohashi University of Technology)

Sub Issue D : Core Design of **Fusion Reactor**

(Leader : Y. Idomura, Japan Atomic Energy Agency)

Posters related to Sub Issue D (Fusion Plasma)

33. Development of Exascale Fusion Plasma Turbulence Simulations for Post-K
(Y. Idomura, T. Ina, K. Obrejan, Y. Asahi, S. Matsuoka, T. Imamura)

34. Communication Avoiding Multigrid Preconditioned Conjugate Gradient Method for Extreme Scale Multiphase CFD Simulations
(S. Yamada, N. Onodera, T. Ina, S. Yamashita, Y. Idomura, T. Imamura)

36. Extended Kinetic-Magnetohydrodynamic Hybrid Simulations of Magnetically Confined Laboratory Plasmas
(Y. Todo, M. Sato, H. Wang, R. Seki)

37. Communication Reduced Multi-Time-Step Algorithm for the AMR-based Lattice Boltzmann Method on GPU-rich Supercomputers
(N. Onodera, Y. Idomura, Y. Ali, T. Shimokawabe)

Posters related to Sub Issue A (Combustion)

67. LES Modeling and Simulation of Coal Gasification on an O_2-CO_2 Blown Coal Gasifier
(H. Watanabe, R. Kurose, K. Tanno)

68. Large-eddy Simulation of a Supercritical CO_2 Combustion Field in a Realistic Combustor
(P. Jain, Y. Iwai, Y. Kobayashi, M. Itoh, T. Nishiie, R. Kurose)

70. Large-eddy Simulation of Combustion Instability of Spray Combustion : Effect of Time Fluctuation of Liquid Fuel Mass Flow Rate
(J. Nagao, A. Pillai, R. Awane, R. Kurose)

73. Fully Coupled Simulation of Coal Gasification System Using LES based Solver for Combustion and Thermal Conduction Solver in Vessel
(T. Yamada, N. Mitsume, H.Watanabe, R.Kurose, H.Uchida, S.Yoshimura)

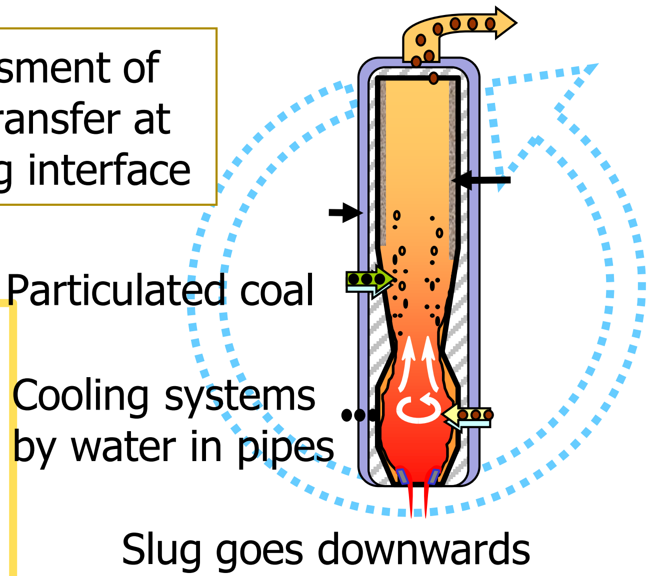
Sub Issue A

Multiscale and Multiphysics Simulations of Coal Gasification Plant Including Reaction (Combustion, Gasification, Particle Tracing, Slug Melting) – Thermal Conduction – Cooling – Deformation

Overview of Coal Gasification Plant

REVOCAP_Coupler : Two-way coupling simulation of thermo-fluid–structure and cooling phenomena

Assessment of heat transfer at coupling interface



Assessment of complex thermo-fluid combustion dynamics

ADVENTURE_Thermal (FEM)
Thermal Conduction in vessel as well as cooling by water in cooling pipes

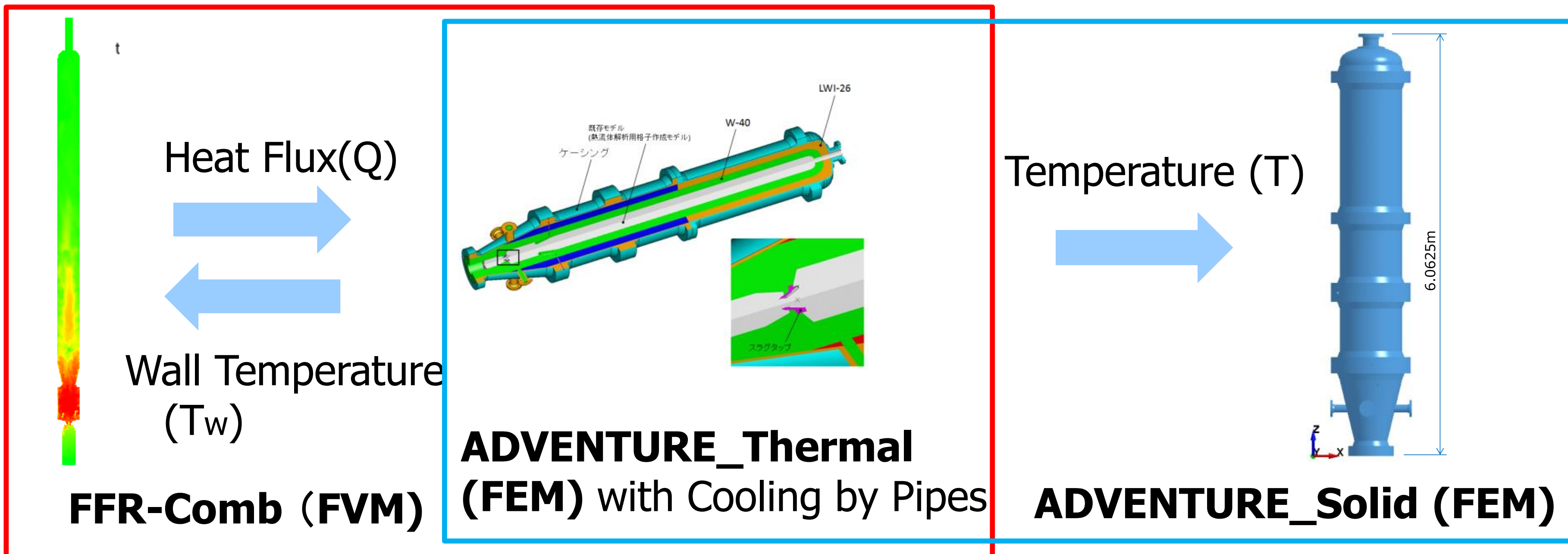
FFR-Comb (FVM) : Combustion, gasification and particle tracing models
Ash solution (solid-gas-liquid three-phase model)

Assessment of elevated-temperature structural integrity

ADVENTURE_Solid (FEM) : Nonlinear material behavior and damage assessment under elevated-temperature and high-pressure environments

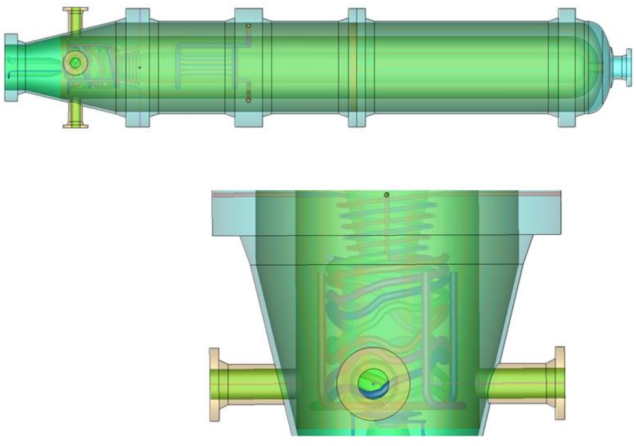
Relations among Applications

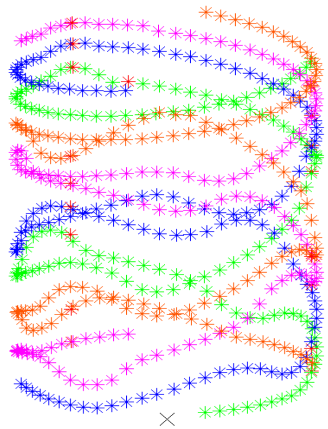
Application	Notes
FFR-Comb (FVM)	Combustion Flow (Gas-Liquid-Particles)
REVOCAP_Coupler #1	Two-way Coupling on K-computer
ADVENTURE_Thermal (FEM)	Thermal Conduction in Vessel and Cooling
EVOCAP_Coupler #2	Off-line One-way Coupling
ADVENTURE_Solid (FEM)	Nonlinear Thermal Fatigue, Structural Integrity



Online Two-way Coupling **REVOCAP_Coupler** Off-line One-way Coupling

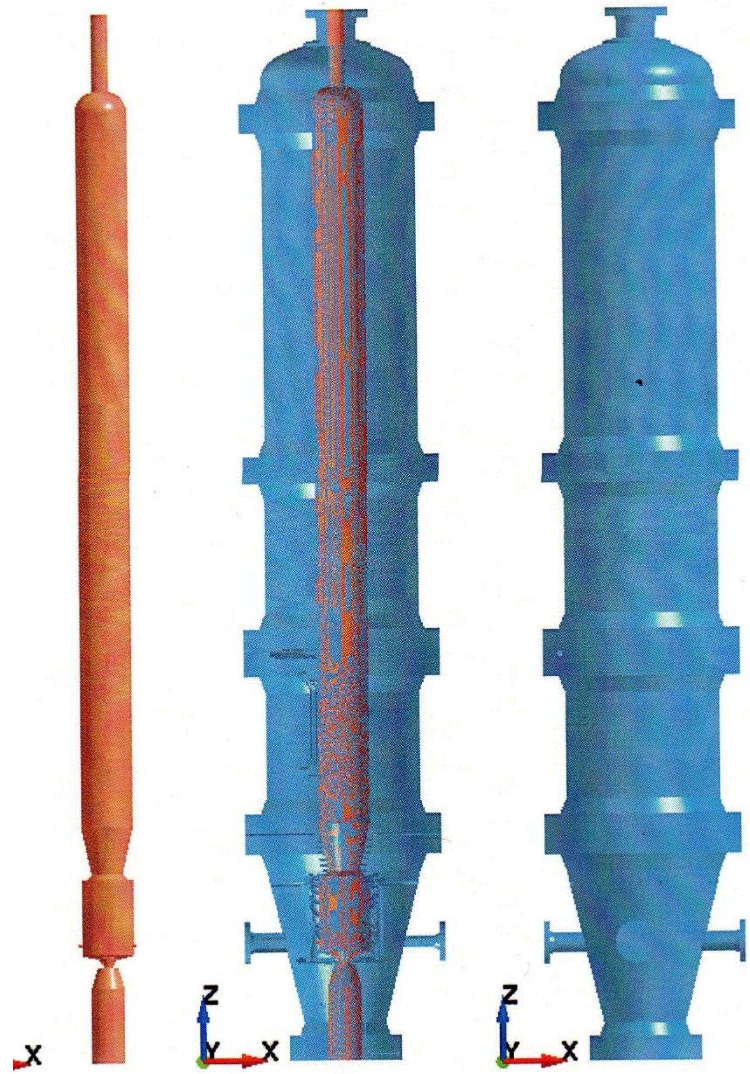
Simulation Modelsn of Combustor, Vessel, Pipes





CAD Model 1D Model of Cooling Pipes

	Fluid model	Solid model
Nodes	23,883,517	25,510,852
Elements	118,803,415	155,999,061
Kinds of Eelements	Tet Prizm Pyramid Hex	Tet
Coupling Nodes	634,678	243,024



Combustion Coupling Meshes Solid

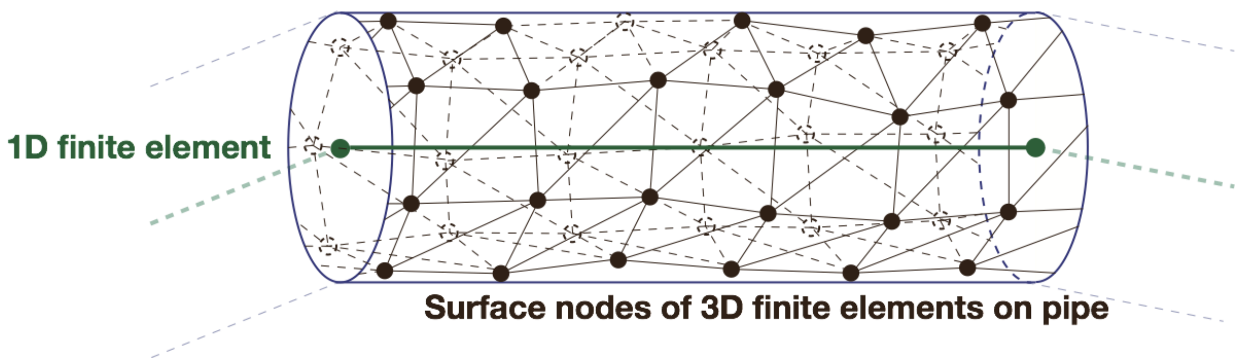
Calculation Conditions of Combustion Flow Region for FFR-Comb

Flow model	Zero Mach Approximation
Turbulence model	DLES
Time integration	Euler Implicit
FD Scheme for convection term	Eq. of Motion：2nd Order Central Difference（95%） Eq. of Energy：2nd Order Upwind
Time increment	5.0×10^{-6} s
Char reaction	C＋0.5O2→CO C＋CO2→2CO C＋H2O→CO＋H2
Gas reaction	CH4＋0.5O2→CO＋2H2 H2＋0.5O2→H2O CO＋0.5O2＋H2O→CO2＋H2O CH4＋H2O→CO＋3H2 CO＋H2O→CO2＋H2
Initial condition	Initial pressure：2×10^6Pa Initial temperature：1273K Initial mass density：5.06kg/m^3 Initial chemical components：N2(57.26%) ＋CO2(18.69%) ＋CO(16.82%)＋C(0.0053%) ＋ASH(0.0056%)
Temperature BC at Wall	Transfer condition, Tw=308K、htc=10.0

CPU Time per Step： 3 sec when using 9216 CPU (1152 nodes)

About 1 M elements
(About 0.24 M nodes)

Coupling between 3D Thermal Conduction in Vessel and 1D Convection & Diffusion in Cooling Pipes



3D thermal conduction

- finite element method
- implicit time integration
- large-scale analysis

Heat flux on pipe surface
↓
Source term of 1D analysis

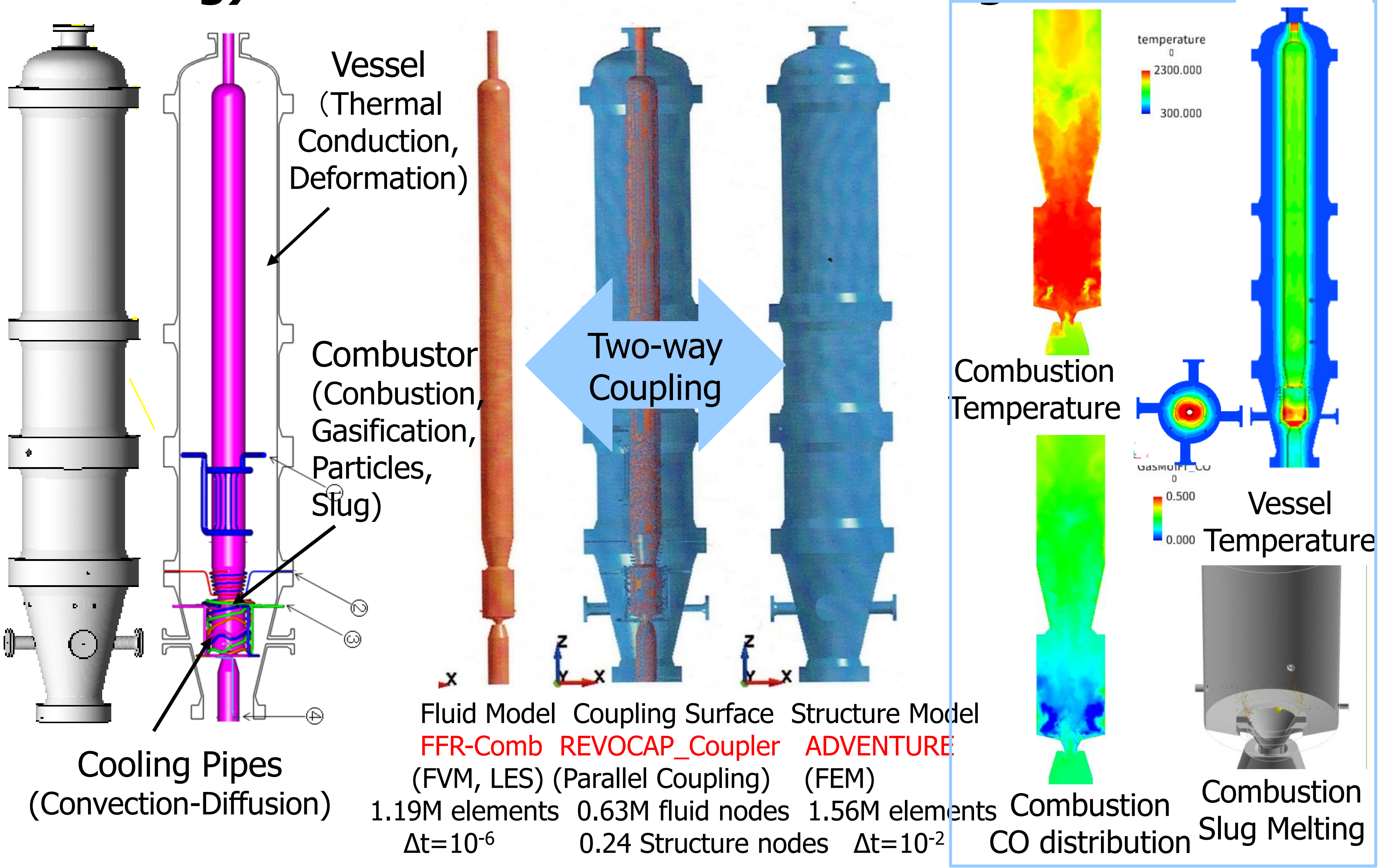
Partitioned coupling scheme

Heat flux given by
heat transfer B.C.

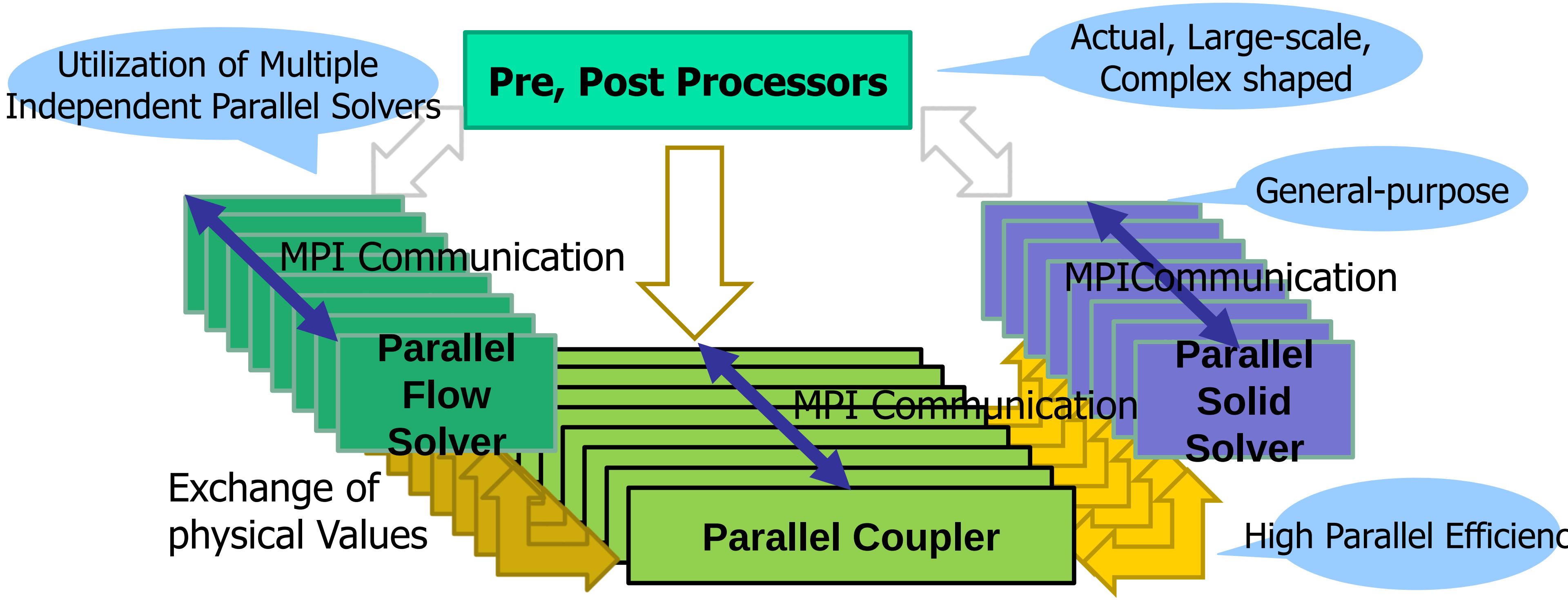
1D cooling pipe model

- local discontinuous Galerkin (LDG) method
- explicit time integration

Multiscale and Multiphysics Simulations of CRIEPI's Coal Gasification Plant Including Reaction (Combustion, Gasification, Particle Tracing, Slug Melting) – Thermal Conduction – Cooling – Deformation



Parallel Two-way Coupling of FFR-Comb ⇔ REVOCAP_Coupler ⇔ ADVENTURE on the K computer



Socket communication➡MPI (Socket version) Socket communication➡MPI (MPI version)

Analysis Case	Solid Subdomains	Time Steps	CPU Time (hrs)	Time for Pre-process ※1(s)	CPU Time for Flow Analysis (s/step)	CPU Time for Thermal Conduction Analysis(s/step)	CPU Time for Others (s/step)	Time for Output (s)
1	128	5000	19	1501.5	2.60	8.97	0.11	107.0
2	2048	15000	25 ※2	2856.8	2.68	0.66	0.13	219.2

Subdomains in Flow Region : 9216 (9216cores(1152nodes))

Sub Issue C

Multiscale and Multiphysics Simulations of Offshore Wind Farm to Evaluate Power Generation Efficiency and Accumulated Fatigue Damages of Blades

Wind Turbine of NREL 5MW

Rotor Operation	Upwind
Number of Blades	3
Rotor Diameter	126 m
Hub Diameter	3 m
Hub Height	90 m
Tip Speed	80 m/s

Tip Speed Ratio In Benchmark Test	7.0

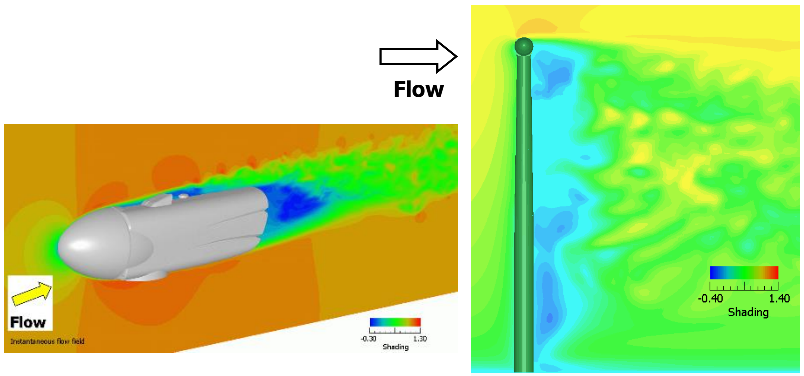
J. Jonkman, S. Butterfield, W. Musial, G. Scott, “Definition of a 5MW Reference Wind Turbine for Offshore System Development”, NREL/TP-500-38060, (2009)

Various Nonlinear Fluid Dynamics Phenomena

- ■Meandering of Wake
- ■Interaction among Turbines via Wakes
- ■Effect of Peeling Flow from Nacelle and Tower onto Wake
- ■Effect of Wake onto Power Generation Efficiency and Structural Reliability

➡ Key Issues in Site Selection, Optimum Design and Arrangement, Operation Cost Reduction

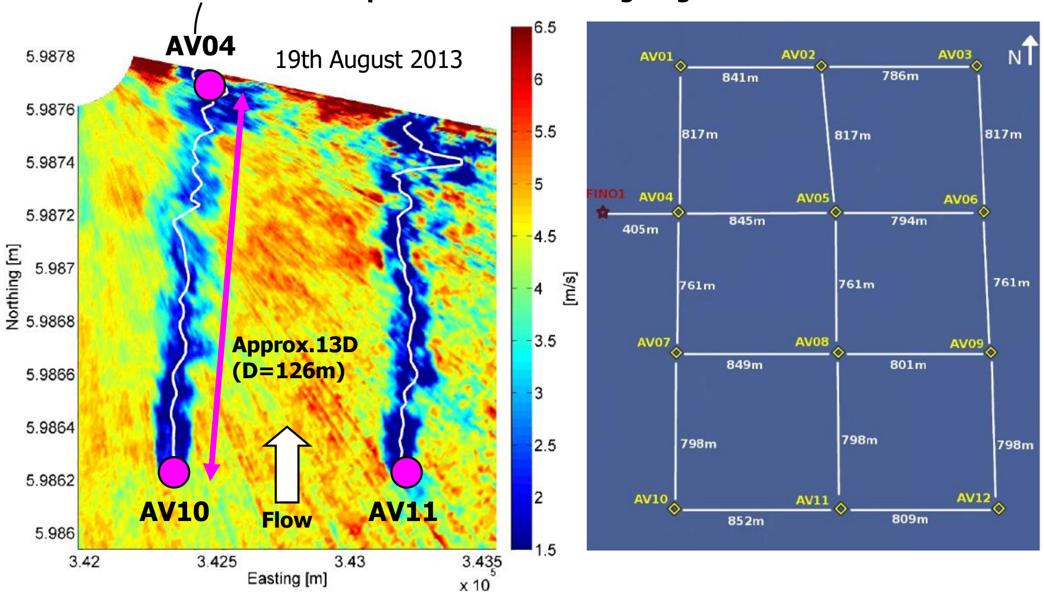
Effect of Nacelle and Tower onto Wake



Effect of tower and nacelle on the flow past a wind turbine by using RIAM-COMPACT

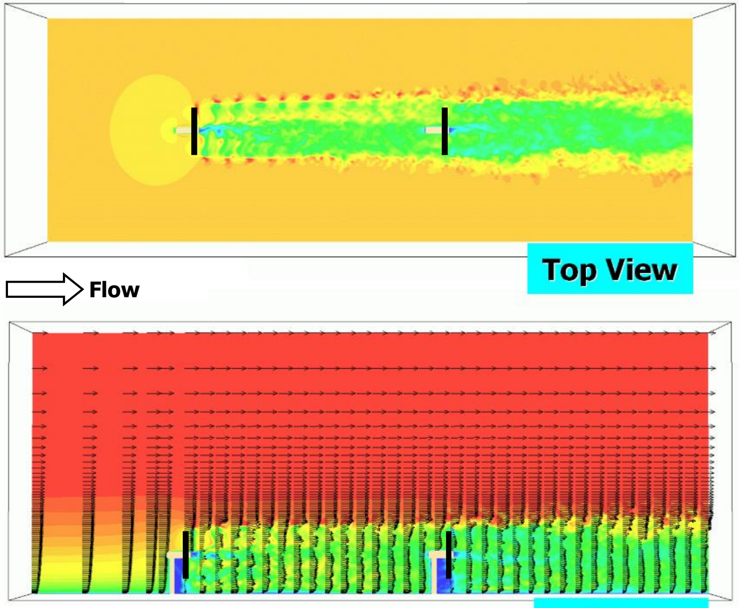
Wake Meandering

Turbine AV04 experiences meandering single wake from AV10.



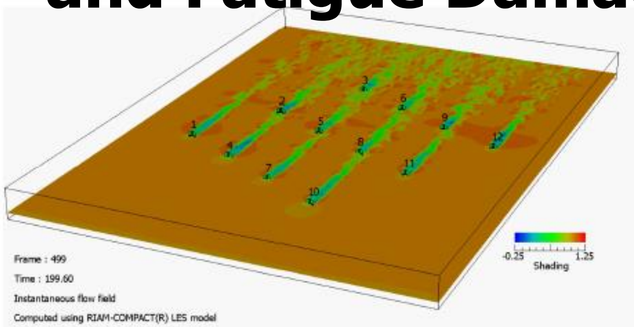
Lidar Scanning (PPI: Plan Peripheral Indicator) at Alpha Ventus Offshore Wind Farm

Wake Interaction



Actuator Line Modeling of Wind Turbine Wakes by using RIAM-COMPACT

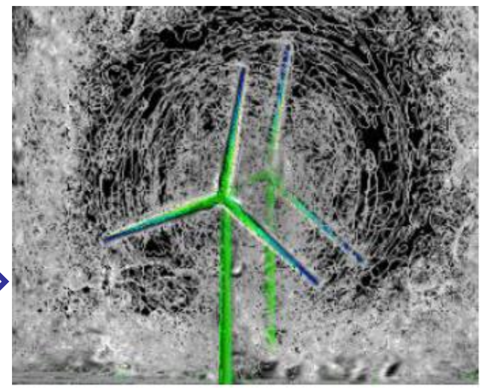
Multiscale and Multiphysics Simulations of Offshore Wind Farm for Evaluation of Power Generation Efficiency and Fatigue Damages of Blades



Precise Comparison
on Wake Effect

RIAM-COMPACT for HPC

・Simultaneous Analyses for 16(24) Wind Directions by Parallel LES Analyses
・Engineering Wake Model
・Hundreds M to B Elements



Two-way Coupling

Blade’s Deformation
(→LES Analysis)

FFB: LES-based Simulation of Tandem-placed Large-scale Wind Turbines

・Over 10 B Elements
・Wall Model

REVOCAP_Coupler

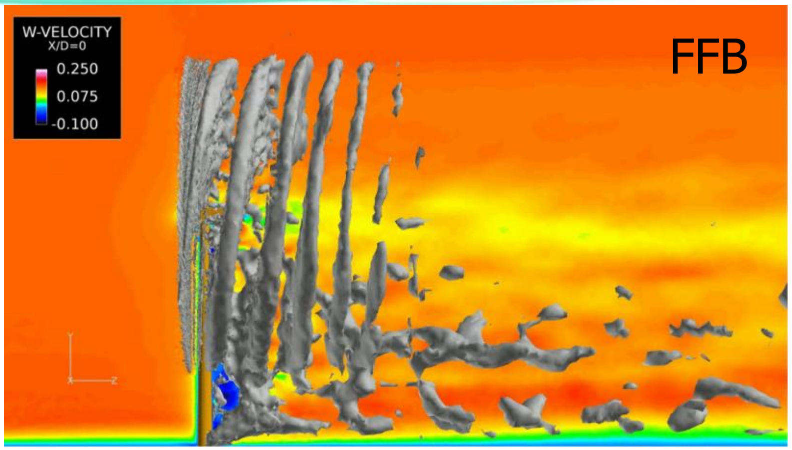
One-way Coupling

Fluid Loading acting to Blades

ADVENTURE_Solid:

・Analysis of Accumulated Fatigue Damage of Blade consisting of Orthogonal Anisotropic Laminated Solid Elements

Off-line One-way Coupling Analyses of NREL5MW Blade



CFD Results (FFB on K computer)

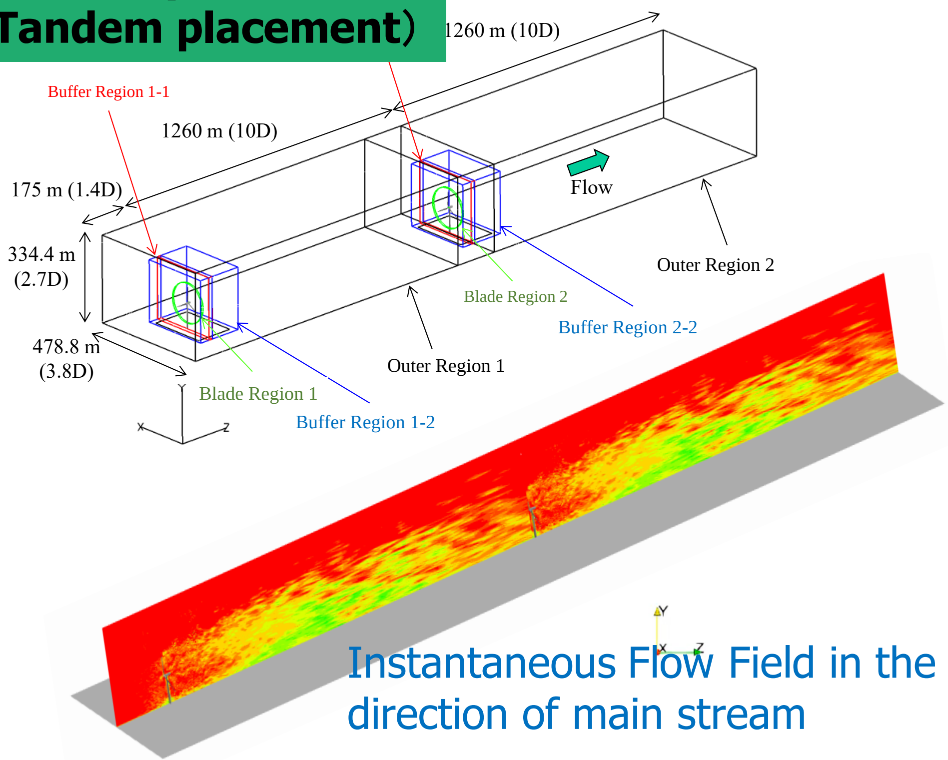
(Abstraction)

Time Variations of Fluid Loading Distributions on the Surface of Blade

REVOCAP_Coupler

Mapping of the above Fluid Loading onto the Surface of Blade Mesh

CFD Analysis Model (Tandem placement)

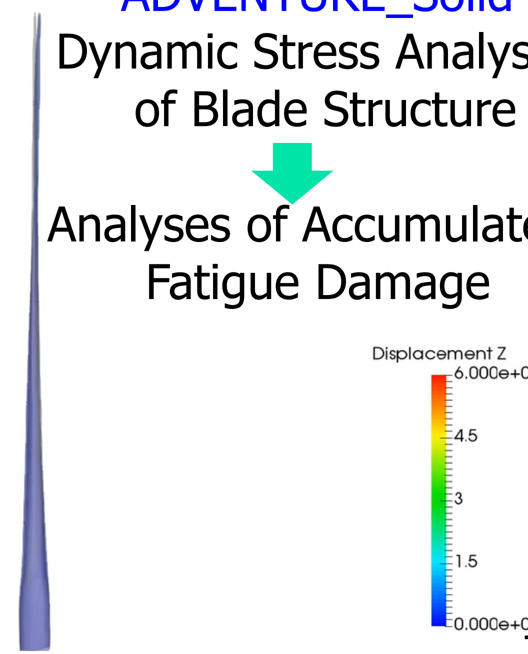


Instantaneous Flow Field in the direction of main stream

ADVENTURE_Solid

Dynamic Stress Analyses of Blade Structure

Analyses of Accumulated Fatigue Damage



Example of Evaluation of Accumulated Fatigue Damage Evaluation

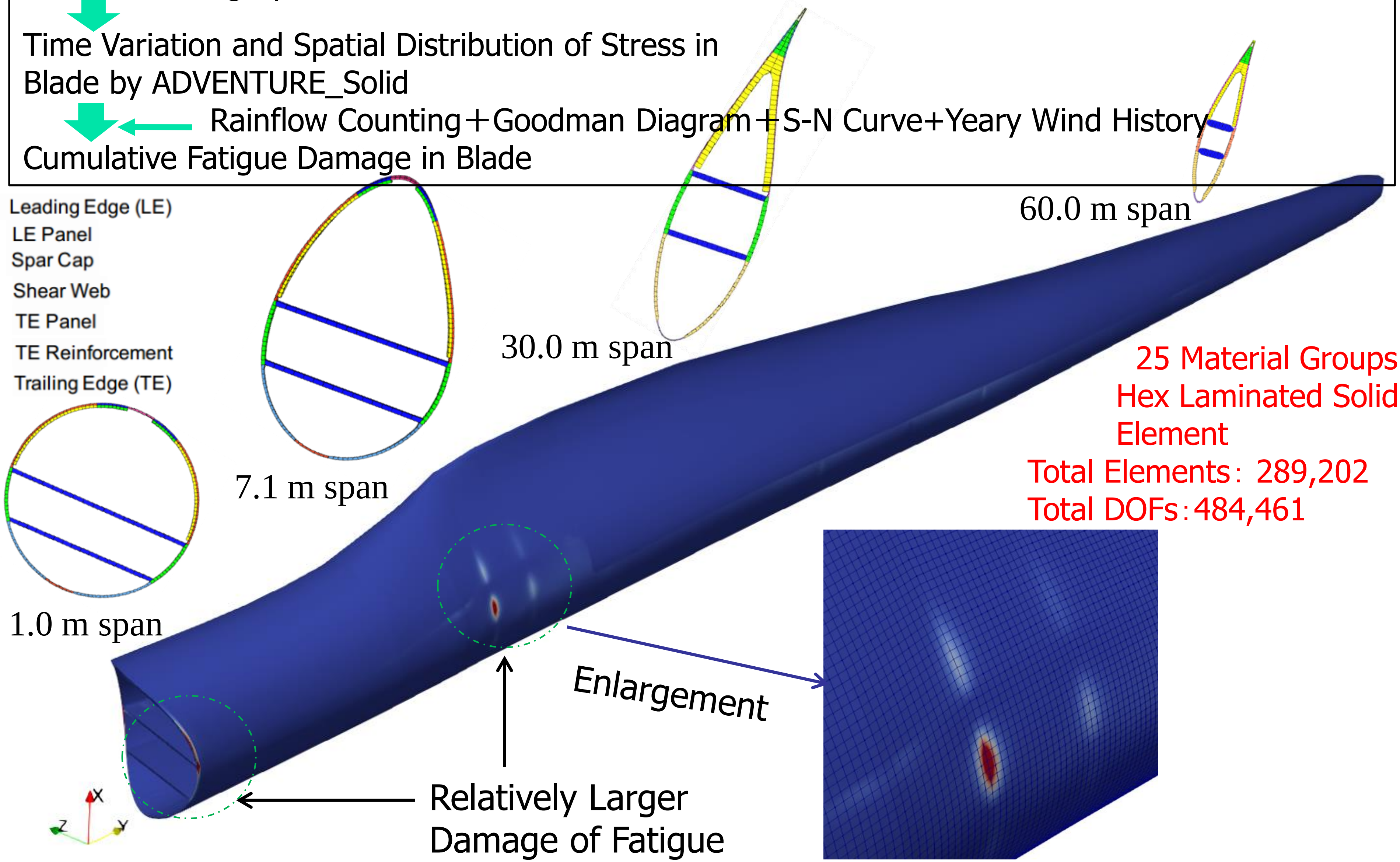
Time Variation and Spatial Distribution of Fluid Loading by FFB on K ← Atmospheric Boundary Layer, Turbulence, Wake

↓

Time Variation and Spatial Distribution of Stress in Blade by ADVENTURE_Solid

↓ ← Rainflow Counting＋Goodman Diagram＋S-N Curve+Yeary Wind History

Cumulative Fatigue Damage in Blade



Thank you for your attention !

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100M ADVENTURE

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